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Enhanced Ultrasonic Characterization of Assemblies, TLL_19

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Graham Thomas and Diane Chinn

Abstract

The solid state bonded joint between two components; called an autoclave bond, is critical to the performance of a weapon system. A nondestructive method to assess the integrity of these joints is needed to certify the weapon for extended life. This project is developing ultrasonic technologies for bond quality assessment. Existing ultrasonic technology easily maps totally unbonded areas in a bond line. As an example, Figure 1 is an ultrasonic image of the bondline in a tensile specimen that was taken from a surrogate autoclave bond. We enhanced this technology to quantify the mechanical properties of a bond. There are situations when a bond interface appears intact by existing inspection methods, but fails under minimal loading. We developed an ultrasonic technique to eliminate this problem and assess the durability of the bond. Our approach is based on advanced signal processing and artificial intelligence techniques that extract information from the ultrasonic signal after it interacts with the bondline. We successfully demonstrated this technique on surrogate samples. We also designed and began assembly of an ultrasonic system to evaluate weapon components. Our next step is to acquire ultrasonic data on real parts and tailor the bond classification algorithm to detect and image defective bond regions.

Introduction

In general, a drawback to diffusion bonding is the lack of a nondestructive method for measuring the strength of the bond (1, 2). Current nondestructive evaluation techniques easily detect total unbonded areas but a low strength bond is usually judged to be a good bond if a total unbond is not present. This work addresses the problem of measuring bond strength. The ultrasonic signal from a diffusion bond contains much information about the condition of the bond. Extracting that information is the goal of this work.

Figure 2 illustrates our approach to extracting bond strength information from the ultrasonic signal. The protocol produces a computer algorithm that will predict bond strength based on subtle changes in the ultrasonic waveforms. The first step was to fabricate samples with varying bond strengths. Ultrasonic data was then acquired from the samples and stored. Next the samples were destructively tested to measure their strengths. To relate the ultrasonic data with bond strength, the digitized ultrasonic signals are processed with various transform techniques to determine frequency content (3,4,5). Changes in the frequency spectra are quantified and a set of features is generated. This feature vector uniquely identifies the ultrasonic signal taken from a known bond sample. The feature sets are analyzed to develop automated algorithms based on statistical and neural network codes (6). These classifiers predict the bond strength by extracting features from the ultrasonics signals that have been reflected by the bond interface. Then the optimal features are processed in a formula that combines the feature values with weighting constants and produces a bond quality number. This resulting bond quality number corresponds to the bond's failure strength.

Experimental Approach

A set of copper to aluminum diffusion bond samples was manufactured to produce samples with different bond strengths. These samples were made by electroplating the surfaces with an interlayer (copper or zinc); applying pressure to hold the substrates together; and elevating the temperature. Less than nominal strength was produced by modifying the previous steps. For example, weak bonds were fabricated by not electroplating the substrates or by not elevating the temperature adequately.

Before acquiring data for evaluating bond strength, totally unbonded areas must be noted. Tradition ultrasonic C-scans were performed on the bond samples and totally unbonded areas were imaged. Ultrasonic data for the process of measuring bond strength were not captured in the unbonded regions.

Ultrasonic waveforms were captured from each of the samples and stored for future processing. A high frequency, broadband transducer sent the ultrasonic energy into the sample and received the energy reflected from the top surface of the specimen and the bond interface. This procedure was done from the copper side and the aluminum side. Many ultrasonic signals were captured on each sample. The location of each signal was recorded so that the strength at that location could be correlated with the signal after destructive analysis.

After acquiring the ultrasonic data, the samples were cut into tensile specimens. These specimens were pulled to failure in a tensile test apparatus and the failure strength was noted. These failure strengths were then correlated with the ultrasonic signals. Thus each ultrasonic waveform corresponded to known bond strength.

To better understand the bonding process, metallographic analysis was conducted on the diffusion bonds. Representative samples from each bond strength were potted and polished. The interface was imaged with a microscope and analysis of the interface correlated the amount of bonding with strength.

Results

We clearly demonstrated that ultrasonic signals contain information that corresponds with bond strength in copper to aluminum diffusion bonded samples. Figure 3 summarizes the results of this work. Example frequency spectra from low (1494 psi), medium (3235 psi), and high (6929psi) strength bonds are displayed in Figure 3. Also for comparison, the frequency spectrum for an area on a sample that was unbonded is shown. The unbonded sample has much more energy than the others because an unbonded area reflects almost all of the acoustic energy. A high strength bond will only reflect the amount of energy predicted by the acoustic impedance mismatch between copper and aluminum. As expected the spectra from the other levels of bond strength fall in between the total unbond and a perfect interface.

The goal of this work is for a computer to automatically predict the bond strength. To do this, the obvious differences in the spectra shown in Figure 3 must be quantified before the computer can predict the strength. One way to characterize the spectra is by measuring the area under the curve for particular frequency ranges. The energy under the curve at 15MHz is a feature that corresponds well with bond strength. Figure 4 plots failure strength verses spectral value at 15 MHz. These results show that the energy at 15MHz decreases as the failure strength increases.

The next task will be to develop an automated classifier that predicts the bond strength based on the optimal features. Statistical and neural network algorithms will process the feature vectors from a training set of ultrasonic data to evolve a diffusion bond classifier that predicts strength.

Conclusions

This work developed an ultrasonic technology to determine diffusion bond quality that will display the bond strength of the autoclave, diffusion bond. After an ultrasonic signal interacts with a bonded interface, it contains information about the quality of the interface. As a surrogate to the materials joined together in an autoclave bond, copper to aluminum diffusion bonds were fabricated with known bond strengths. Ultrasonic data from these known samples were analyzed to determine characteristics of the signal that corresponded to changes in bond strength. An example of a characteristic that correlated with bond strength is the acoustic energy at 15 MHz. The numerical value of this feature decreased monotonically as the bond strength increased.

These encouraging results prompted us to perform the same procedure on uranium to beryllium diffusion bonds that is an improved surrogate material system. The materials were acquired and a bonding facility was built. No bonded samples have been produced yet.

An ultrasonic scanner for evaluating weapon components has been designed and is partially assembled.

Though this task is directed at autoclave bond evaluation, this ultrasonic technique works well for pinch welds, reservoir welds, and adhesive bonds also. The data processing and analysis approach can provide a method to characterize materials. For example, ultrasonic nondestructive evaluation measures engineering modulus, senses small voids, and sizes grains.

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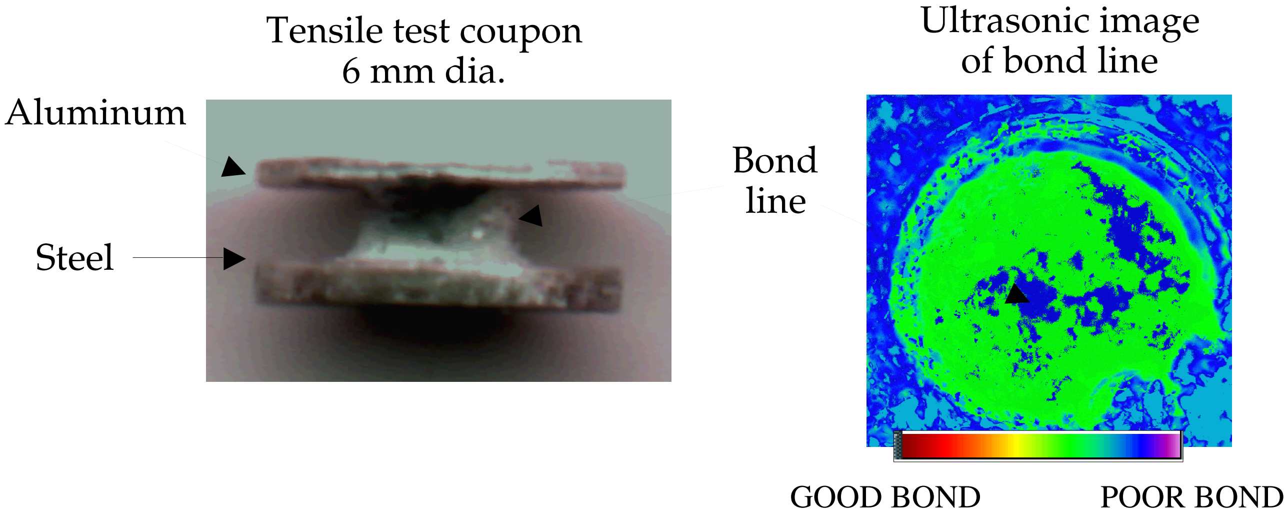

Figure 1. Traditional high resolution ultrasonic C-scans image total unbonds in tensile specimens from surrogate autoclave bonds. This evaluation ensures that the sample preparation has not damaged the tensile specimen and thus invalidating the results.

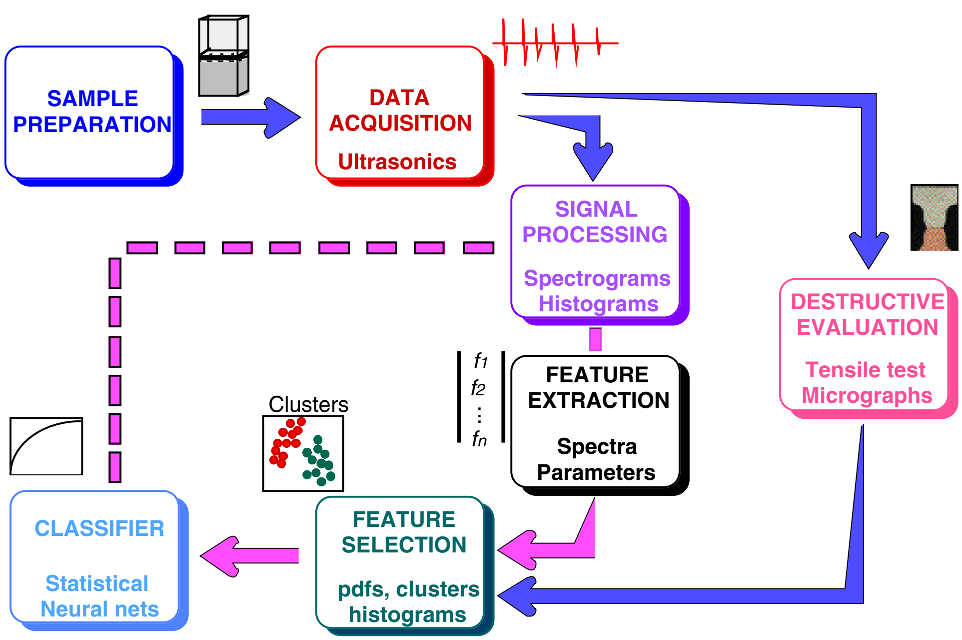

Figure 2. Protocol for bond strength classification trains an algorithm to predict diffusion bond strength based on subtle differences in the ultrasonic signals reflected by the bond.

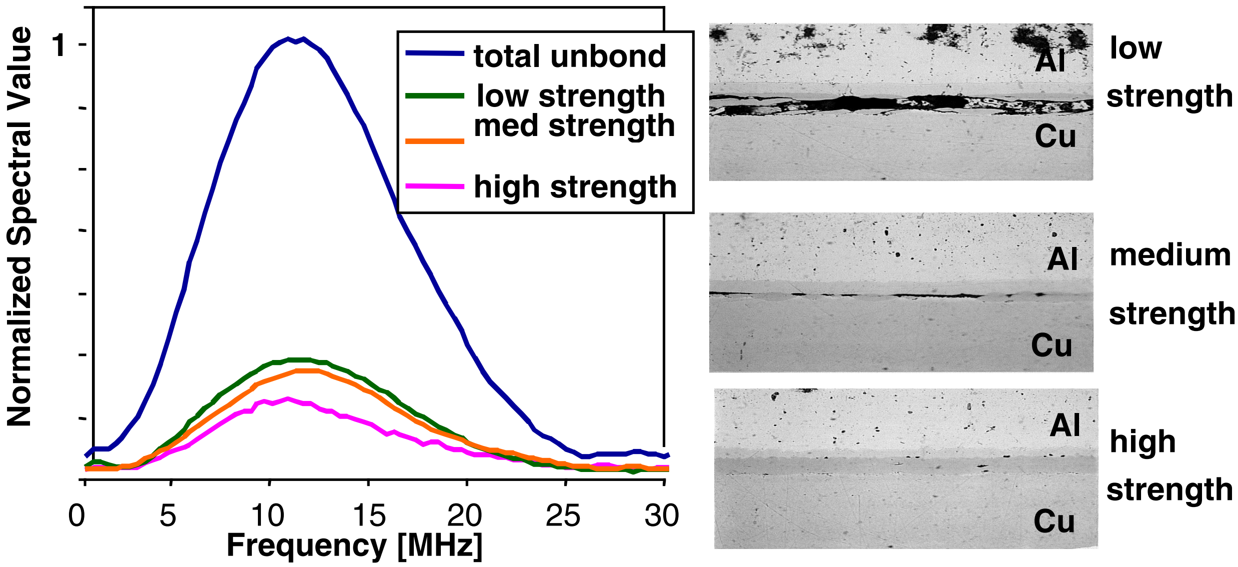

Figure 3. Frequency spectra from ultrasonic signals reflected from diffusion bonds shows decreasing spectral value for increasing bond strength. Also shown are micrographs of the various strength bonds.

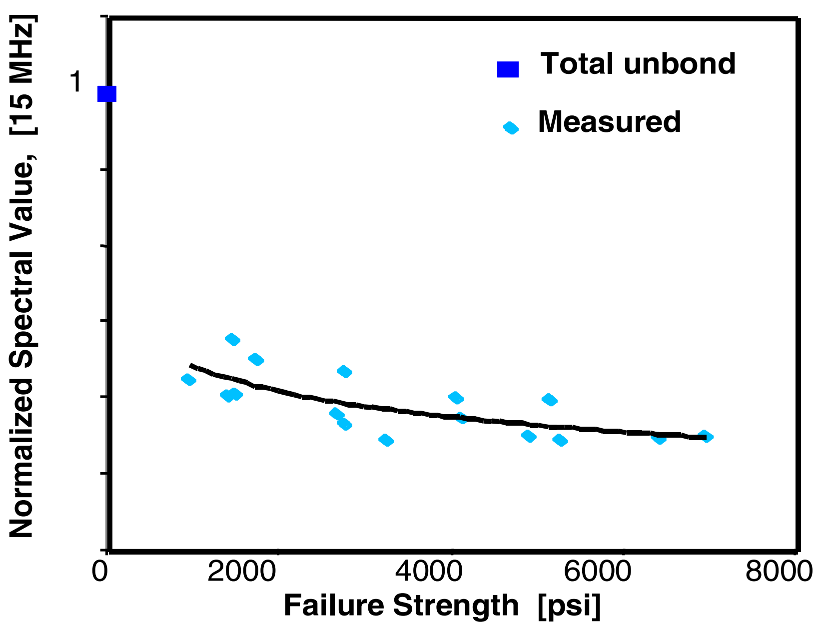

Figure 4. Spectral energy at 15 MHz decreases as the bond strength increases. The signal from the unbonded area has an extremely large amount of acoustic energy and thus is detectable by standard ultrasonic techniques.

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